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EDITORIAL

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Nature provides us with many examples of complex materials, ranging from relatively passive, near equilibrium structures such as wood and bone to highly active, far from equilibrium systems such as migrating cells. Living cells are kept out of equilibrium in large part by metabolic processes and energy-consuming enzymes such as *molecular motors* that generate forces and drive the machinery behind cell locomotion and many other cellular processes; molecular motors are also the basis of muscle contraction at the macroscopic scale. Increasingly, reductionist efforts to create simplified model systems based on living cells have led to a better understanding of their inner workings. At the same time, such efforts have inspired many researches to explore more widely the physics and chemistry of "active states of matter", including those of non-biological origin.

Such work offers many promising avenues for creating novel materials with tunable properties. Many of the relevant materials, just like the cell, are highly deformable soft solids or viscoelastic fluids. Some, such as dilute suspensions of motile bacteria, at first might be mistaken for simple fluids; but they are far from simple. For instance, while adding conventional (inactive) colloids to a simple solvent can only increase its viscosity, the addition of active particles such as bacteria can reduce it.[1] And when such particles interact in suspensions at higher density, remarkably complex behaviour can emerge, ranging from an almost complete loss of viscosity[2] to spontaneous chaotic flow sometimes called 'bacterial turbulence'.[3]

The growing interest of physicists, chemists and materials scientists (alongside biologists) in such systems has given rise to a growing sub-field of *Active Soft Matter*, whose breadth, dynamism and variety is reflected in the papers that appear in this themed issue. Within it, various aspects and manifestations of activity are explored in biological or biologically inspired systems. These range from the nanometre or single-molecule level to the near macroscopic level of collective behavior, and represent many different avenues and approaches to the study of active soft matter.

Activity can manifest itself in dynamic patterns, such as vortices or asters, in which stiff filaments radiate out from a common center,[4] in analogy with the formation of mitotic spindles of stiff biopolymers in the case of dividing cells. Even in the case of simplified *in vitro* constructs such as are studied in this issue, however, such pattern formation is often highly dynamic,[5] and of a strongly non-equilibrium origin, although the resulting static structures can be reminiscent of liquid crystalline order. In addition to non-equilibrium pattern formation, molecular motor activity in polymer solutions and gels can lead to striking changes in their mechanical properties, such as enhanced fluidization[6,7] or its opposite: active stiffening by orders of magnitude.[8] From a materials perspective, this suggests novel mechanisms for active control of material behaviour, in particular viscoelastic properties, by enzymatic activity. In this issue, the effects of activity on viscoelasticity are explored in systems ranging from highly simplified *in vitro* constructs to living cells and even tissues. In addition to mechanical and viscoelastic effects, local motor activity also leads to non-thermal fluctuations,[9,10] which are also studied in this issue.

At a more discrete level, the motion of individual active particles, or modest numbers of these, continues to surprise. This is true particularly of hydrodynamic interactions, which are capable of completely altering the steady state behaviour of interacting motile particles in suspensions,[11] in a fashion that is forbidden for non-active particles such as Brownian colloids (whose steady states are given by the Boltzmann distribution, which is blind to those interactions). As described in two reviews in this issue, hydrodynamics also (i) strongly constrains biological and material-design strategies for creating locomotion in particles too small for their inertia to effectively compete against viscosity (*i.e.*, at the micron scale and below in water), and (ii) leads to unexpectedly subtle synchronization effects between

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otherwise independent swimming objects. Furthermore, as also discussed in this issue, hydrodynamics influences the rectifying effect of the ratchet-potentials utilized by molecular motors and other directional propulsion systems.

Thus, ideas delineated above—pattern formation and viscoelasticity at the continuum level, and hydrodynamic interactions among discrete active components—are recurrent concepts in active soft matter. Yet the interdisciplinarity and breadth of the subject is also reflected in the fact that other contributions in this issue defy any simple classification. Rather than list them all here, we urge readers to explore for themselves the breadth of science covered.

There remain many challenges ahead for this field. One of these is to create much stronger conceptual bridges between naturally occurring structures and synthetic ones—for instance by engineering synthetic motors that can be designed, or instructed, to carry out tasks different from those already achieved by naturally occurring examples. These tasks might include the directed assembly of new materials that nature has not yet thought of. A second challenge is to tie more closely to experimental systems (biological or otherwise) the important progress already made in the continuum theoretical descriptions of active systems with nematic or polar order. Such descriptions generally contain various material parameters (such as bending constants) whose values are quite narrowly specified for equilibrium systems such as molecular liquid crystals, but which are much less understood for some of the active examples of interest (bacterial suspensions, for instance). A third task is as follows. Having extracted from biology some of the thematic ideas of the subject, and having developed these through '*in vitro*' experiments, '*in silico*' simulations, and fundamental theory, it is important before long to carry these new insights back towards the biological realm. Indeed, the full biological implications of the active soft matter paradigm—as developed by physical scientists—are probably extensive. These implications are now ripe for further exploration.

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